From Actively Compliant Lightweight Robots to Intrinsically Compliant System

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***Abstract*—Robots with active compliance, as for example torque-feedback controlled light-weight robots at DLR have reached high levels of maturity and performance. Their potential with respect to safety aspects in physical human-robot interaction as e.g. collision detection and reaction is shown. Current work focuses now on intrinsically compliant systems, presumably having advantages like compliance bandwidth. A novel joint prototype that realizes such passive compliance is presented and evaluated.**

I. Actively Compliant Lightweight Robots

THE robotic systems developed at DLR (arms, hands, and the humanoid manipulator Justin) are designed for interaction with humans in unstructured, everyday environments. Typical applications are assembly processes and service duties in which a robot works in immediate vicinity of humans and possibly in direct physical cooperation with them (Fig. 1). For Justin (and its arms and hands) we developed a set of impedance controllers which are based on a unified, passivity based approach that accesses the joint torque interface.

Each joint of the robot is equipped with a torque sensor between the gear and the link. This torque measurement after the gears is essential for implementing high-performance soft-robotics features. When implementing compliant control laws, the torque signal is used both, for reducing the effects of joint friction and for damping the vibrations related to the joint compliance. Motor position feedback is used to impose the desired compliant behavior.

II. Collision Detection and Reaction

Using a light-weight robot as the LWR-III we have shown how collision detection and reactive control strategies can significantly contribute to ensuring safety to the human during physical interaction [1], [2]. Several collision tests were carried out, illustrating the feasibility and effectiveness of the proposed approach.

III. From Actively Controlled to Passive Compliance

The limitations of the achievable compliance by active control especially become an issue when considering the protection of the robot joint from external overload [3]. This is due to the limited sensor precision, model accuracy, and sampling time as well as the motor saturation. This threat can be diminished by deliberately introducing mechanical compliance into the joint. Furthermore, future robotic systems are supposed to execute tasks with similar speed and dexterity to humans. Therefore an elastic element is inserted in the joint between the motor and the link.

Fig. 1. DLR Justin interacting in a human environment at the Automatica 2008 fair.

An elastic element in the joint serves as an energy storage mechanism, possibly decreasing the energy consumption of the entire system during the task execution, e.g., when playing drums or during running. Furthermore, the stored energy can be used to considerably increase the link speed. In contrast to the active compliance case, the robot remains compliant even in the case of deactivation or malfunction of the joint, thus potentially increasing the safety of humans interacting with the robot and protecting the robot joint from external impacts.

IV. Intrinsically Compliant Hardware Design Concept

The simplest intrinsically compliant joint realization has a fixed spring behavior, usually with a constant [4] or progressive stiffness characteristic. This results in a significant loss of link motion bandwidth and accuracy. To reduce this effect, the stiffness of the joint has to be adaptable to the desired task, requiring a second actuator.

Current work at DLR regarding robot arm joints is focused on a setup, in which one motor changes the link position and the other one the link stiffness almost independently [5]. Mechanical compliance is introduced by a spring mechanism. This system leads to reduced dynamic losses.

In this presentation we want to discuss one of the realized approaches in [5]: The **Variable Stiffness Joint (VS-Joint)** as outlined in [6]. Its high power joint motor changes the link position. The joint motor is connected to the variable stiffness mechanism and the link in a differential gear setup (Fig. 2). The joint stiffness is adjusted by the significantly smaller and lighter motor, changing the characteristic of the supporting mechanism.

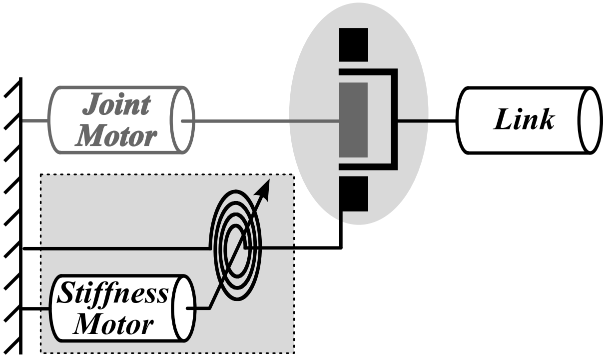

Fig. 2. Principle of the variable stiffness joint mechanics. The circular spline of the harmonic drive gear is supported by the new mechanism.

V. Experimental Validation of VS-Joint Performance Gain

The application of throwing a ball is a good example to show the performance enhancement gained by the VS-Joint in terms of maximal velocity (Fig. 3). For throwing a ball as far as possible, it has to be accelerated to the maximum achievable velocity and released at a 45° angle. A speed gain of 265% for the link velocity between stiff and compliant joint was achieved in the test increasing the throwing distance from 0.8 m to 6.0 m.

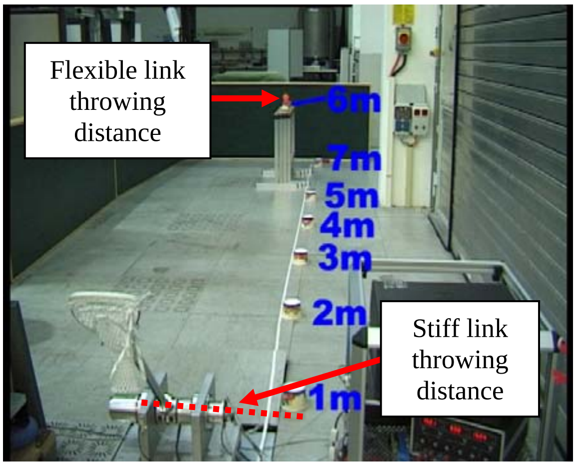

Fig. 3. Throwing distance of a ball with a flexible link using energy storage in the springs (6.0 m) and a stiff link (0.8 m).

References

[1] A. De Luca, A. Albu-Schäffer, S. Haddadin, and G. Hirzinger, Collision Detection and Safe Reaction with the DLR-III Lightweight Manipulator Arm, *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS2006)*, Beijing, China, 2006, pp. 1623–1630.

[2] S. Haddadin, A. Albu-Schäffer, A. De Luca, and G. Hirzinger, Collision Detection & Reaction: A Contribution to Safe Physical Human-Robot Interaction, *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS2008)*, Nice, France, 2008, pp. 3335–3363.

[3] S. Haddadin, T. Laue, U. Frese, and G. Hirzinger, Foul 2050: Thoughts on Physical Interaction in Human-Robot Soccer, *IEEE/RSJ Int. Conf. Intelligent Robots and Systems (IROS2007)*, San Diego, 2007, pp. 3243–3250.

[4] M. M. Williamson, Series Elastic Actuators, *A.I. Technical Report No. 1524*, Massachusetts Institute of Technology, Cambridge, Massachusetts, 2005.

[5] A. Albu-Schäffer, O. Eiberger, M. Grebenstein, S. Haddadin, C. Ott, T. Wimböck, S. Wolf, and G. Hirzinger, Soft Robotics, *Robotics & Automation Magazine, IEEE*, Volume 15, Issue 3, September 2008, pp. 20–30.

[6] S. Wolf and G. Hirzinger, A new variable stiffness design: Matching requirements of the next robot generation, *IEEE Int. Conf. on Robotics and Automation (ICRA2008)*, Pasadena, USA, 2008, pp. 1741–1746.